CONTAMINANT EXPOSURE AND EFFECTS—TERRESTRIAL VERTEBRATES DATABASE: TRENDS AND DATA GAPS FOR ATLANTIC COAST ESTUARIES

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Abstract. In order to examine the condition of biota in Atlantic coast estuaries, a "Contaminant Exposure and Effects—Terrestrial Vertebrates" database (CEE-TV) has been compiled through computerized search of published literature, review of existing databases, and solicitation of unpublished reports from conservation agencies, private groups, and universities. Summary information has been entered into the database, including species, collection date (1965–present), site coordinates, estuary name, hydrologic unit code, sample matrix, contaminant concentrations, biomarker and bioindicator responses, and reference source, utilizing a 98-field character and numeric format. Currently, the CEE-TV database contains 3699 geo-referenced records representing 190 vertebrate species and >140,000 individuals residing in estuaries from Maine through Florida. This relational database can be directly queried or imported into a Geographic Information System to examine spatial patterns, identify data gaps and areas of concern, generate hypotheses, and focus ecotoxicological field assessments. Information on birds made up the vast majority (83%) of the database, with only a modicum of data on amphibians (<0.1%). Of the >75,000 chemical compounds in commerce, only 118 commonly measured environmental contaminants were quantified in tissues of terrestrial vertebrates. There were no CEE-TV data records in 15 of the 67 estuaries located along the Atlantic coast and Florida Gulf coast. The CEE-TV database has a number of potential applications including focusing biomonitoring efforts to generate critically needed ecotoxicological data in the numerous "gaps" along the coast, reducing uncertainty about contaminant risk, identifying areas for mitigation, restoration or special management, and ranking ecological conditions of estuaries.

1. Introduction

The Biomonitoring of Environmental Status and Trends (BEST) program of the U.S. Department of the Interior seeks to identify and understand the effects of environmental contaminant stressors on biological resources, particularly those under their stewardship (Zylstra 1994). The BEST program, which evolved from the historic National Contaminant Biomonitoring Program of the Fish and Wildlife Service (Schmitt and Bunck 1995), currently entails applied research, technical assistance, synthesis, and monitoring activities to provide information to natural resource managers, scientists and the public for use in research, management and conservation. The monitoring component of BEST includes both *active* field collection and analysis of biological samples from broad geographic regions, and *passive* retrospective compilation and analysis of extant data from diverse

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sources. Despite extensive use of estuarine habitat by terrestrial vertebrates, at present there is no active temporally or spatially replicated contaminant monitoring program for the Atlantic coast. In the context of retrospective analysis of data by the BEST program, herein we report an evaluation of contaminant exposure and effects data of amphibians, reptiles, birds and mammals in or near 67 Atlantic Coast and Florida Gulf coast estuaries, in an effort to identify trends and data gaps, to focus and prioritize future field monitoring efforts, and to rank the apparent condition of these ecosystems. This information will be used by the BEST program, and presumably other monitoring programs, as a decision support tool for conducting ecological risk assessments.

2. Methods

2.1 DATA ACQUISITION

Retrospective contaminant exposure and effects data collected since 1965 for free-ranging terrestrial vertebrates residing along the Atlantic coast was identified and retrieved. This entailed computerized searches of published scientific literature using Wildlife Review, BIOSIS®, AGRICOLA, TOXLINE®, Fisheries Review, and Aquatic Sciences and Fisheries abstracts. Information was also compiled from several federal government databases including the Ecological Incident Information System of the U.S. Environmental Protection Agency, the Environmental Contaminant Data Management System of the Fish and Wildlife Service, and the Wildlife Health Diagnostics and Epizootiological Databases of the U.S. Geological Survey. In addition, more than 125 scientists and administrators in federal and state environmental and natural resource agencies, conservation organizations, and academic institutions were contacted and forwarded correspondence requesting data.

Source documents were reviewed to identify contaminant exposure and effects data collected within estuarine drainages and zones. Unless obvious flaws in data quality were detected, all information was coded for database entry. All information was spatially referenced with the sample collection location and geographic coordinates. When coordinates were not provided in a source document, they were determined from the name or location description of the collection site using MapExpert® version 2.0 (DeLorme Mapping, Freeport, ME). In the event samples were collected across an entire county or state, the coordinates of the county seat or state capital were assigned to the record. When both individual observations (raw data) and summary statistics (mean, median) were provided in a document, only summary data were coded for entry.

2.2 CONTAMINANT EXPOSURE AND EFFECTS—TERRESTRIAL VERTEBRATES DATABASE

A database of geographically-referenced contaminant exposure and effects information was created using dBase® for Windows, version 5.0 (Borland International Inc., Scotts Valley, CA). Using a 98-field character, numeric, and memo format, a data record includes an identification number, common and scientific name of species, date of sample collection (month and year), location of collection site (site name, Atlantic coast state, and geographic coordinates), name of estuary, U.S. Geological Survey hydrologic unit code, sample matrix analyzed (e.g., liver, egg, brain), number of samples, concentration of unique contaminants (13 organochlorine pesticides, total PCBs, 18 PCB congeners, 8 dioxins, 10 dibenzofurans, and 20 metals, metalloids and trace elements), concentration units, presence of a contaminant (organophosphorus pesticide, carbamate pesticide, petroleum), biomarker or bioindicator response data, explanation and comment fields for miscellaneous information, and the source of the information. Information in the CEE-TV database may be searched, sorted and queried.

2.3 USE OF GEOGRAPHICAL INFORMATION SYSTEM FOR CEE-TV DATABASE ANALYSIS

A subset of the CEE-TV database was selected, containing only the unique record identifiers (i.e., identification number) and the geographic coordinates (i.e., latitude and longitude fields), and saved as an ASCII file. Arc/Info 7.1.1® (Environmental Systems Research Institute, Inc., Redlands, CA 1997) was then used to generate a map of points from the ASCII file. Arc/Info was then used to join the rest of the CEE-TV database to the newly generated map, so that each map point was linked to the attributes of the corresponding CEE-TV record. A second map was then created by deleting those records for which geographic location was assigned to a state capital or county seat during data entry.

The second map was then projected from the geographic coordinate system to the Albers Equal-Area Conic Projection. The CEE-TV map was used in combination with state boundary maps, estuarine drainage maps (National Oceanic and Atmospheric Administration 1998), and national wildlife refuge and national park boundary maps to determine the number of CEE-TV records in Atlantic coast states, estuaries, and U.S. Department of Interior properties. ArcView 3.1® (Environmental Systems Research Institute, Inc., Redlands, CA 1998) was used to plot the data by date, species, matrix, and contaminant residues to analyze spatial and temporal gaps in the data, and spatial and temporal trends in contaminant residues. ArcView® Spatial Analyst® was used to generate maps of the geographic density of CEE-TV records within a 30 km buffer zone of the shoreline for the whole database, and for the records categorized by decade.

3. Results and Discussion

3.1 SOURCE MATERIAL AND DATABASE ATTRIBUTES

As of December 1998, the CEE-TV database contained 3699 records and required 4.2 megabytes of storage space. Because a source document often contained data from multiple sampling dates, locations, species, and matrices, several database records were often derived from a single source document. Thus, the number of source documents totaled 891 (204 scientific journal publications, peer-reviewed conference proceedings and books, 3 graduate thesis and dissertation documents, 315 necropsy reports, 34 reports from other sources, and 335 records from other databases).

The 3699 records in the CEE-TV database contain data from 157,381 samples that were frequently quantified for multiple contaminant exposure and effect endpoints. The number of samples per record ranges from 1 to 37,590 with 51% of the records containing greater than 1 sample per record. Often several sample matrices were quantified in a single individual, and in some instances, pooled tissue samples were analyzed; accounting for this uncertainty, the number of organisms in the database is estimated to be 140–150,000. A total of 32 different sample matrices were quantified, with rank order of the six most commonly analyzed being liver > egg > brain > carcass > muscle > adipose.

The collection site of a significant number of CEE-TV records (1546 or 41.8%) was described in only general terms in the source document, and accordingly geographic coordinates (county seat, state capital) were assigned. Often this reflects the nature of the particular investigation (e.g., surveys of broad regions), the status of the species studied (e.g., hesitancy to report exact location of a threatened or endangered species), or the quality of information in another database (e.g., location described only as county and state), although in some instances it can be concluded that the absence of exact sample collection location was an oversight.

The date of sample collection was not specified in source documents for 241 records. From those source documents with complete collection date information, the distribution of records among decades is: 4% from the 1960s; 43% from the 1970s; 29% from the 1980s; and 24% from the 1990s. The apparent decline in number of records over the past three decades presumably reflects restrictions in the use of highly toxic and persistent contaminants, which has lowered the priority of ecotoxicological threats to wildlife for many natural resource managers.

3.2 PHYLOGENETIC TRENDS

The CEE-TV database contains information for 190 terrestrial vertebrate species. Mammals constitute 10.9% of the records, with representation from 6 of 9 orders found in North America (Table I). More than 83% of the database records include

Table I
Phylogenetic distribution of records in the Contaminant Exposure and Effects—Terrestrial Vertebrates Database

Class	Order	Number of CEE-TV Records (% of total)
Mammalia		405 (10.9%)
	Didelphimorphia (New World opossums)	3
	Insectivora (shrews and moles)	8
	Chiroptera (bats)	10
	Rodentia (rodents)	30
	Carnivora (true carnivores)	277
	Artiodactyla (even-toed ungulates)	77
Aves		3096 (83.7%)
	Gaviifomes (loons)	42
	Pelecaniformes (pelicans and allies)	105
	Ciconiiformes (herons, storks and allies)	343
	Anseriformes (waterfowl)	814
	Falconiformes (diurnal birds of prey)	578
	Galliformes (fowl)	8
	Gruiformes (cranes, rails and allies)	185
	Charadriiformes (shorebirds, gulls and allies)	362
	Columbiformes (pigeons and doves)	25
	Cuculiformes (cuckoos)	6
	Strigiformes (owls)	108
	Coraciiformes (kingfisher)	1
	Piciformes (woodpeckers and allies)	1
	Passeriformes (song birds)	482
	Records containing several avian orders[a]	36
Reptilia		196 (5.3%)
	Crocodylia (alligators)	62
	Testudines (turtles)	124
	Squamata (lizards)	1
Amphibia		2 (<0.1%)
	Urodela (salamanders)	1
	Anura (frogs and toads)	1

[a] Mortality incidents involving species of several phylogenetic orders.

avian exposure and effects data for 14 of 21 North American orders of birds. The rank of avian groups (% of total records) is waterfowl (22.0%) > birds of prey (15.6%) > song birds (12.0%) > shorebirds and gulls (9.8%) > herons and storks (9.3%). Reptiles constitute 5.3% of the records; geographically, no records are found for states north of New York. Only 2 records in the database (<0.1%) contained information on amphibians. The paucity of contaminant exposure data for this vertebrate class is well-recognized (Hall and Henry 1992), and despite recent alarm of a worldwide decline in amphibian populations, we are aware of only a few contaminant monitoring studies that have been initiated.

3.3 CONTAMINANT AND BIOMARKER TRENDS

Source documents yielded terrestrial vertebrate exposure data for 26 organochlorine pesticides and metabolites, 37 other chlorinated hydrocarbons, 30 metals, metalloids and trace elements, 3 petroleum hydrocarbons and mixtures, 13 anticholinesterase pesticides, 5 rodenticides, 1 avicide, 1 fungicide, 1 herbicide, and 2 shot materials used in hunting waterfowl. Organochlorine pesticide and metabolite data are found in nearly half of the records, while other organochlorine contaminants (total PCBs, PCB congeners, dioxins, dibenzofurans, octachlorostyrene), and metals, metalloids and trace elements, are each found in over one-third of the records (Table II). Thus, source documents provided a great deal of information on a very limited subset (N=118 substances, compounds and mixtures detected in tissues) of the more than 75,000 chemicals in commerce in the United States (Environmental Defense Fund 1997).

A number of temporal trends in contaminants in the CEE-TV database have been examined. For example, the concentrations of *p,p'*-DDE, and to a lesser degree total PCBs, in avian eggs has declined since the 1970s (e.g., osprey, *Pandion haliaetus;* Figure 1), presumably reflecting restrictions imposed on use of these compounds. Coincident with the temporal decline in the concentration of many organochlorine pesticides and their metabolites in birds, records in the CEE-TV database indicate an increase in anticholinesterase pesticide exposure and mortality in waterfowl and passerines (1970–79: 3 records; 1980–89: 25 records; 1990–1998: 110 records), presumably reflecting increased use of these compounds and more efficient reporting of such die-off events.

Biomarker and bioindicator response information is included in 10.7% of the database records, with temporal trends documenting their increased use over time (e.g., twice as many records in the 1990s compared to the 1970s). In terms of level of biological organization, 66% of these measurement endpoints are at or below the subcellular level (inhibition/induction of enzyme activity, altered concentrations or characteristics of proteins, porphyrins and DNA), while the remainder encompass measurement of avian eggshell thickness.

Table II

Select contaminant exposure and effects information in database.

Measurement Endpoint	Number of CEE-TV Records (frequency in database records)	
Organochlorine Pesticides and Metabolites		1845 (.498)
p,p'-DDD + *p,p'*-DDE + *p,p'*-DDT	1730	
Dieldrin	1067	
Oxychlordane	450	
trans-Nonachlor	344	
Mirex	312	
Hexachlorobenzene	231	
Other Organochlorine Contaminants		1395 (.377)
Total PCBs (aroclors)	1372	
PCB Congeners	105	
Dioxins + Dibenzofurans	26	
Anticholinesterase Pesticides		136 (.037)
Metals, Metalloids and Trace Elements		1293 (.350)
Mercury	792	
Lead	634	
Cadmium	328	
Zinc	208	
Selenium	177	
Shot Used in Hunting		113 (.03)
Petroleum Hydrocarbons		23 (<.01)
Biomarker/Bioindicator Effect Responses		397 (.107)
Cholinesterase Activity	168	
Eggshell Thickness	132	
Protoporphyrin Concentration	32	
δ-Aminolevulinic Acid Dehydratase Activity	17	
Plasma Enzyme Activity	20	
Cytochrome P450	8	

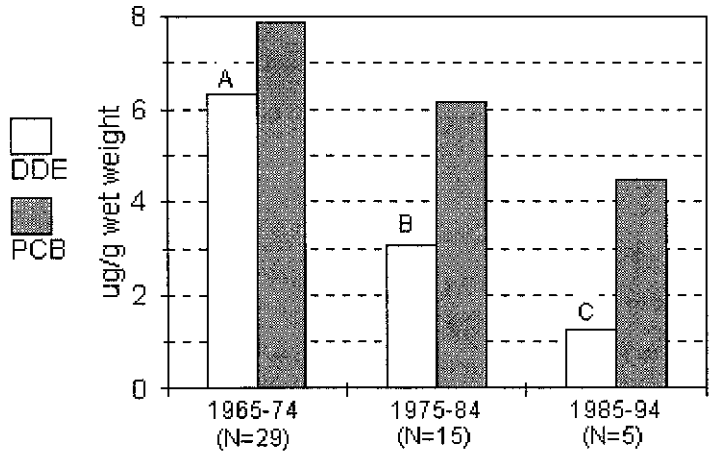

Figure 1. *Geometric mean concentrations of p,p'-DDE and total PCBs in eggs of ospreys collected along the Atlantic coast. Records (N) were grouped by collection date and log-transformed values were compared by analysis of variance. Bars with different letter designations are significantly different ($p<.05$) by the Newman-Keuls multiple range test.*

3.4 SPATIAL TRENDS

The distribution of records among 15 Atlantic coast states plus the District of Columbia indicates that Florida (including Atlantic and Gulf coasts) and New York contained the most ecotoxicological data for wild terrestrial vertebrates (Figure 2). New Hampshire, Rhode Island, and the District of Columbia contained the least data. Although the size and shoreline length of a state has a bearing on the number of records, the available data for these 2 states and the District of Columbia is quite small (≤ 1 record / year) considering the 33-year span of the database.

Of the 3699 records, source documents provided specific locations of 2153 records, of which 2052 records were located within 30 km of the shoreline. These records were most dense between Cape Cod, Massachusetts and the Chesapeake Bay (Figure 2). However, dense clusters of records occurred in South Carolina, Georgia, and Southern Florida. Using ArcView® Spatial Analyst®, geographic density of data records for 30% of the study area was sparse (<1 record/ 1000 km^2) or absent altogether.

Fifteen of the 67 estuaries along the Atlantic states and Florida Gulf coast, comprising 6.8% of the estuarine drainage area, apparently contained no records whatsoever (viz., Saco and Wells Bays, ME; Hampton Harbor, NH; Waquoit Bay, MA; Delaware Inland Bays; Maryland Inland Bays; New River, NC; Broad River, SC; Ossabaw Sound, GA; St. Marys River/Cumberland Sound, Rookery Bay, Suwannee River, and St. Andrews, Choctawhatchee and Perdido Bays, FL).

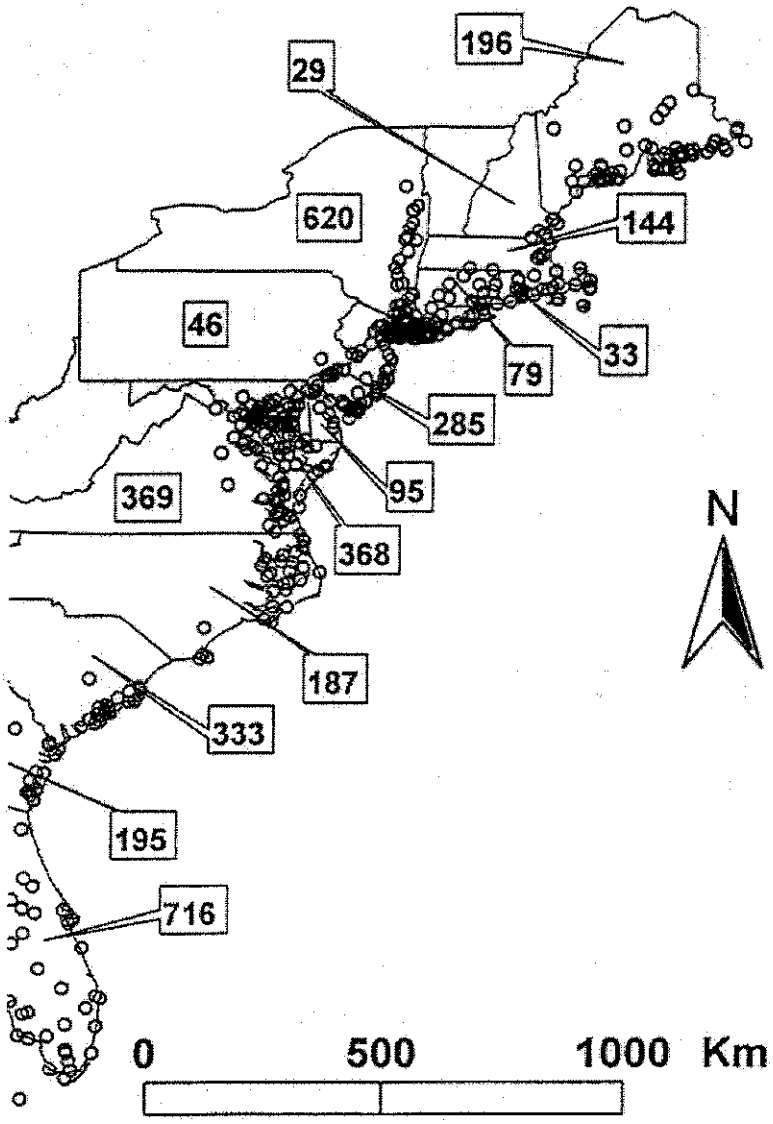

Figure 2. *Geographic distribution of CEE-TV records in Atlantic coast states (District of Columbia has 1 record; location of Gulf Coast of FL records not shown).*

There are 92 National Wildlife Refuges (NWRs) and 76 National Parks (NPs) situated within the 30 km estuarine buffer area (Figure 3). Most property of the Department of the Interior have CEE-TV data records within 10 km of their boundary. However, many NWRs have no database records within 1 km of their boundaries; the largest of these are the Lower Suwannee NWR in FL, Cedar Island

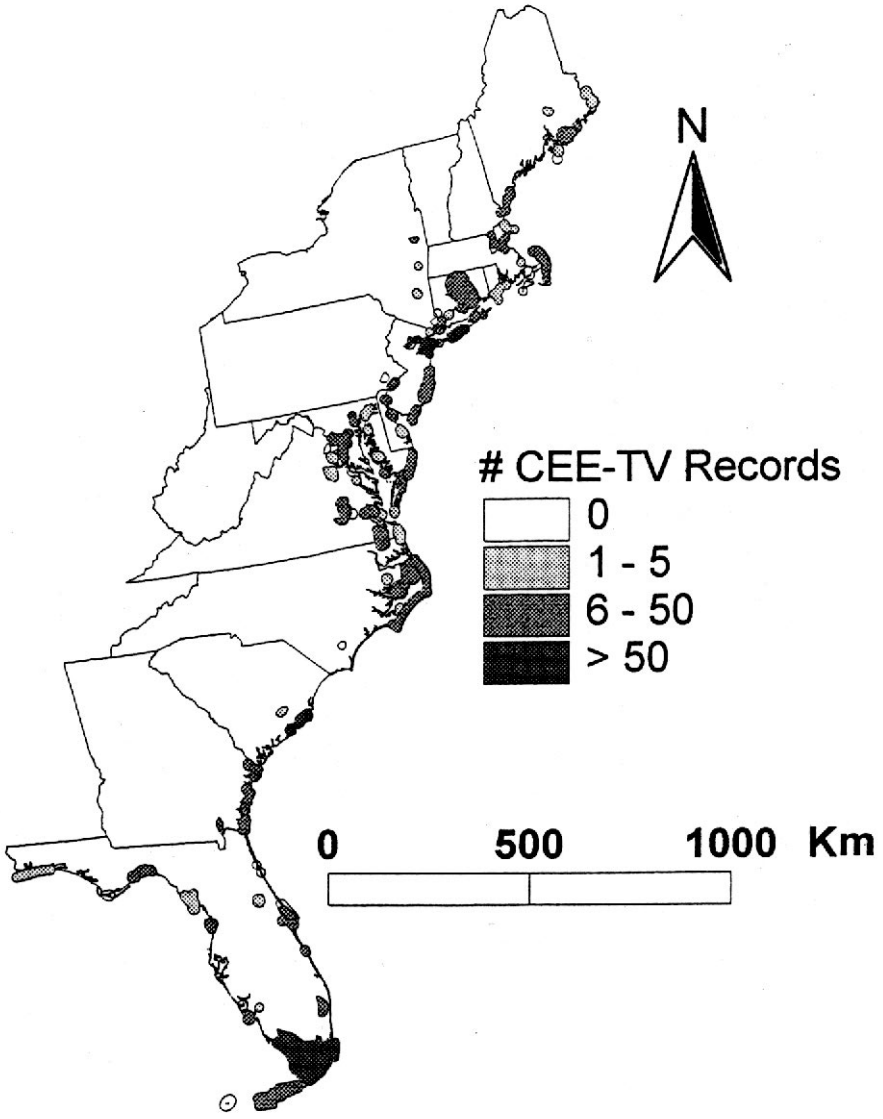

Figure 3. *Frequency of occurrence of CEE-TV records within 10km of National Wildlife Refuges and National Parks, within 30 km of the shoreline.*

NWR in NC, Back Bay NWR in VA, St. Vincent NWR in FL, and Crocodile Lake NWR in FL. Remarkably, there are no terrestrial vertebrate contaminant exposure or effects data for the Rachel Carson NWR. Similarly, several NPs contained no CEE-TV data within 1 km of their borders, the largest being Canaveral National Seashore in FL, Cape Lookout National Seashore in NC, Prince William Forest Park in VA, George Washington Memorial Parkway in VA, and Manassas National Battlefield Park in VA.

4. Conclusions and Applications

Through *passive* retrospective compilation of contaminant exposure and effects data for terrestrial vertebrates, several phylogenetic, contaminant, and spatial trends and data gaps for estuarine habitat have been identified. These trends, in conjunction with other extant data layers (e.g., human populations, pesticide use, occurrence of sensitive species, hazardous waste sites and contaminated habitats), can be used by the BEST program to focus *active* biomonitoring efforts. One of the goals of these new biomonitoring efforts should be to generate spatially and temporally consistent ecotoxicological data to better assess the threat of environmental contaminants to terrestrial vertebrates. In addition, the CEE-TV database may be used as a decision support tool for natural resource managers to reduce uncertainty about contaminant risk, evaluate possible areas for marsh restoration, mitigation or special management, and to direct attention to areas where problems are likely to develop in the future. Finally, as part of an integrated assessment, the CEE-TV ranking of estuaries could be compared with other schemes emanating from databases on water quality assessment (U.S. Environmental Protection Agency 1998), submerged aquatic vegetation maps, and waterbird atlases (Erwin and Korschgen 1979) to determine the significance of toxicological signatures to overall estuarine condition.

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